DOCUMENT RESUME

ED 469 635 SE 066 945

| | |
|---|---|
| AUTHOR | Brand, Judith, Ed. |
| TITLE | Antarctica: Scientific Journeys from McMurdo to the Pole. |
| INSTITUTION | Exploratorium, San Francisco, CA. |
| SPONS AGENCY | Bank of America Foundation. |
| ISSN | ISSN-1536-9471 |
| PUB DATE | 2002-00-00 |
| NOTE | 21p.; Theme issue. Published quarterly. |
| AVAILABLE FROM | Exploratorium, 3601 Lyon Street, San Francisco, CA 94123. E-mail: exploring@exploratorium.edu. |
| PUB TYPE | Collected Works - Serials (022) -- Reports - Descriptive (141) |
| JOURNAL CIT | Exploratorium Magazine; v26 n2 spec iss Sum 2002 |
| EDRS PRICE | EDRS Price MF01 Plus Postage. PC Not Available from EDRS |
| DESCRIPTORS | Astronomy; Biological Sciences; *Biology; *Climate; Elementary Secondary Education; Foreign Countries; *Physical Sciences; *Science Education |
| IDENTIFIERS | Antarctica |

ABSTRACT

This issue of Exploratorium Magazine focuses on Antarctica. Antarctica has one of the most extreme climates in the world with an untouched environment inviting researchers with great opportunities for study. This issue describes the journey of four Exploratorium staff members to frozen Antarctica. Chapters include: (1) "Life at the Bottom of the World"; (2) "Try This! Dress the Scientist"; (3) "South Pole Astronomy"; and (4) "Ground Truth." (YDS)

Reproductions supplied by EDRS are the best that can be made
from the original document.

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY
K. Feichtmeir
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
2B

# Antarctica

## Scientific Journeys From McMurdo to the Pole

ED 469 635

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

expl○ratorium

Special Expedition Issue!

BEST COPY AVAILABLE

exploratorium

Vol. 26, No. 2 Summer 2002

*The Exploratorium Magazine* is produced quarterly by the Exploratorium, a museum of science, art, and human perception. The magazine communicates ideas that exhibits can't easily demonstrate, extending the museum beyond its physical walls. Each issue takes an in-depth look at a single topic, explaining the underlying science of the everyday world.

*The Exploratorium Magazine* is free to museum Members. Selected articles appear in the online version of the magazine at www.exploratorium.edu/exploring

**Editor:** Judith Brand
**Art Director:** Mark McKowan
**Design:** Tally Rogerley
**Production Editors:** Elyn Hament and Martha N. Steele
**Production:** Alisa Fowden
**Photographers:** Paul Doherty, Mary K. Miller and Noel Wanner
**Photo Editor:** Martha N. Steele
**Membership Director:** Rachel Erickson
**Publisher:** Dr. Robert Semper

**Editorial Board**
Dr. Paul Doherty (Teller), Co-Director, Teacher Institute
Dr. Karen E. Kalumuck, Biologist, Teacher Institute
Ruth Brown, Director, Editorial & Media Resources
Kurt Feichtmeir, Learning Tools Manager
Michael Pearce, Curator

**Exploratorium Board of Directors**
William K. Bowes, Jr., *Chairman*, Ann S. Bowers, G. Steven Burrill, Anna M. Chavez, George W. Cogan, Gail Cogan, Richard A. DeMillo, James M. Duffany, Sculli G. Eichmann, Elizabeth Asip Evans, Lyn G. Fritz, Barbara Glasser, Adele J. Goldberg, James H. Herbert II, Charles M. Hobson, David A. Kane, Daniel E. Koshland, Jr., C. Richard Kramlich, Julius R. Krevans, Lucia L. Lanza, Jude P. Laspa, Gary Lauder, G. Robert Muehlhauser, Ruediger Naumann-Etienne, Howard N. Nemerovski, Clyde W. Ostler, Donald L. Paul, Vincent J. Ricci, E. Parson Smith, Jr., H. Marcia Smolens, Allison Williams; *Chairman Emeritus*: F. Van Kasper; *Board of Directors Emeritus*: William K. Coblentz, Paul M. Cook, Wolfgang Panofsky, Peter G. Wendell

**Advisory Council**
Natalie Angier, J. Michael Bishop, Ramon Cortines, Susan Weeks Coulter, Ann Druyan, Marta Larraechea de Frei, James F. Gibbons, Donald A. Glaser, Linda Darling-Hammond, Robert M. Metcalfe, Gordon E. Moore, Arno Penzias, William J. Rutter, Larry W. Sonsini, Chang-Lin Tien, Bill Viola

Please direct editorial correspondence to *Exploratorium Magazine*, c/o the Exploratorium, 3601 Lyon St., San Francisco, CA 94123
E-mail address: exploring@exploratorium.edu

ISSN #1536-9471 © 2002 The Exploratorium

FIRST WORD

# SCIENCE AT THE EXTREMES

Origins

Science learns its best lessons at the extreme. That's because extreme situations tend to eliminate many of the variables that make the study of nature overly complex.

What has always amazed me about Antarctica, however, is how many areas of science find this particular extreme environment a significant research site. Physicists working on the AMANDA project, for example, have buried sensors deep in the Antarctic ice to track elusive high-energy neutrinos. Biologists there study fish that live in water so cold that normal blood freezes. Astrophysicists find the South Pole a perfect place for observing cosmic rays, and geologists keep careful watch on Mount Erebus, a volcano that erupts almost continuously.

For the past few years, the Exploratorium's *Origins* project has been exploring the special places where researchers are working on answering the big questions of science. While we may hear about their discoveries in the news, most of us will never visit these places in person, or get a firsthand look at what it takes to make these discoveries. *Origins* offers virtual field trips to places of current scientific research—places like Antarctica.

With one of the most extreme climates on the planet, the isolated, untouched environment of Antarctica is truly unique. It is for this reason that the National Science Foundation (NSF) supports and maintains major research facilities at McMurdo Station and the South Pole. The effort requires incredible logistical support, from overseeing construction of the new South Pole research station to loading the annual supply ship with food, clothing, and equipment for hundreds of people working in Antarctica.

For this *Origins* project (2001/2002), we had our own complex logistics to work out. We sent four staff members with tons of special equipment to Antarctica to create a field trip for the rest of us. Producers Mary Miller and Noel Wanner, senior scientist Paul Doherty, and videographer extraordinaire Julie Konop made up the team.

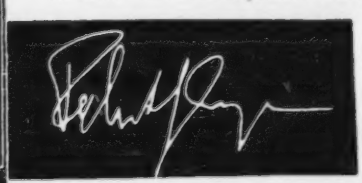
This was no simple trip. Mary, Julie, Paul, and Noel were "on the ice" for six weeks, and traveling for another two. Their Web dispatches, photos, and interviews—carried live via video connection to the Exploratorium—provided a real-time window onto the world of doing science. You can see the team's adventures archived at www.exploratorium.edu/origins/antarctica. The images and articles in this magazine also originated largely from their work.

At the Exploratorium, project director Melissa Alexander and Webcast studio manager Robyn Higdon, along with a great media production crew, gave us all the opportunity to visit this amazing place in real time and talk to the people there. Web producer Robin Marks and Web designer Jenny Villagran worked with writers and media specialists to create an online home for the project. On the museum floor, graphic designers, exhibit developers, and events staff introduced the public to the project and kept us connected with the exploits of the team. By the time we were done, we'd produced and presented forty-one Webcasts in forty-one days.

South X Pole

We are grateful for the support of the Antarctic Artists and Writers Program, National Science Foundation Office of Polar Programs, and to Guy Guthridge and the staff of Raytheon Polar Services, who provide support for NSF in Antarctica. We also want to acknowledge the National Science Foundation, the McBean Family Foundation, and AboveNet Communications, Inc., for their generous support of *Live@ Exploratorium: Origins*.

We hope you enjoy the ongoing experiences the *Origins* series offers—online, at the museum, and in this impressive field report.



Rob Semper, Executive Associate Director

BEST COPY AVAILABLE

## the crew

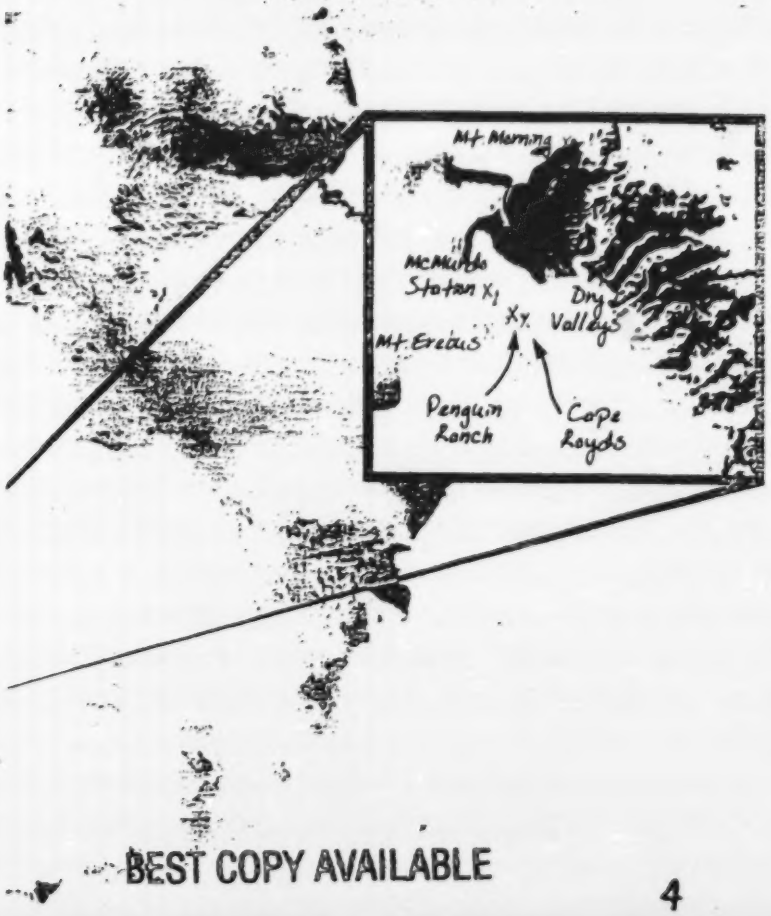
Going to Antarctica was a lifelong dream for biologist and producer Mary K. Miller. She wasn't the first in her family to visit the frozen continent: Mary arrived twenty-five years to the day after her father flew an Air Force plane from California to McMurdo Station.

An adventurer and poet, Exploratorium producer Noel Wanner says Antarctica completely captivated him. "Antarctica shines in my mind, blazing sun and dark rock. What a strange journey. I want to go back, but I fear I'll never see it again."

For the past four years, Julie Konop has been collecting video and broadcasting live shows from around the world. In Antarctica, she also reached the pinnacle of her snowmobile-riding ecstasy on the Ross Ice Shelf on Christmas day.

Physicist and writer Dr. Paul Doherty is also an accomplished mountaineer. Paul says it gave him great joy to be able to use his knowledge and skills in the extreme conditions of Antarctica.






## contents

2 LIFE AT THE BOTTOM OF THE WORLD
Penguin Ranch, Dry Valleys
by Mary K. Miller

6 TRY THIS! DRESS THE SCIENTIST
by Taffy Keighley

8 SOUTH POLE ASTRONOMY
South Pole
by Noel Wanner

12 GROUND TRUTH
Mount Morning, Mount Erebus, Dry Valleys
by Paul Doherty

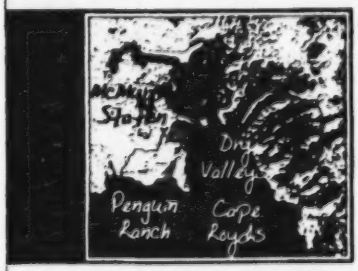
17 EXPLORATORIUM SUPPORTERS CREDITS

BEST COPY AVAILABLE

*Gymnodraco acuticeps*

# LIFE AT THE BOTT

by Mary K. Miller



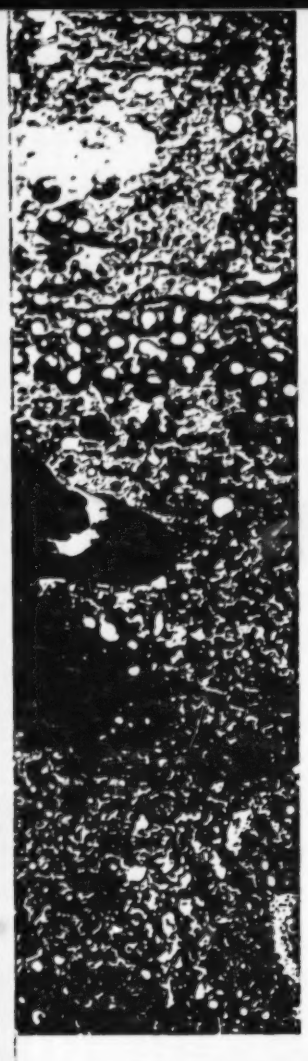

It's been months since my first Antarctic scuba dive and I'm still having a hard time fathoming the experience. Although I've been a scientific and recreational diver for twenty years, almost everything about diving under the ice was surprising and new. Certainly, I'd anticipated that the water would be very cold. Although it was December—summertime in Antarctica—the sea was just under the temperature at which fresh water will freeze (the saltiness of the ocean lowers its freezing temperature). But I had a specially designed diving suit with watertight seals that kept my body dry, and under the dry suit were layers of insulating undergarments to keep me warm.

As I descended through a dive hole cut into the six-foot-thick (2-m-thick) sea ice of McMurdo Sound, I felt like an astronaut floating through a ship's portal into space. Holding the safety line, I glanced up at the rough underside of the ice. Huge jagged crystals hung from the ice ceiling, surrounded by bubbles and darting little fish. But my destination was the sea floor, seventy-five feet (25 m) below, and I turned away from the ice and started kicking for the bottom.

I'd come to Antarctica as one of a four-member team from the Exploratorium to investigate and report on research at this remote scientific outpost. As part of our mission, I was diving with a team of biologists to learn about and document their work with fishes that have adapted to life in this extreme environment.

What I experienced under the Antarctic ice was unlike anything I'd ever encountered before—a dim, fluid world that seemed endless. The clarity of the water surpassed that of any tropical sea, with about nine hundred feet (300 m) of visibility. One could easily think that life in this freezing water would be lethargic and scarce, but the sea was teeming with active creatures both familiar and strange.

Sea stars, anemones, fish, and sponges covered the rocky reef, some looking like typical California kelp-forest species while others were bizarre, like nothing I'd ever seen. A palm-sized crustacean called a sea cockroach swam by me on its back, its legs pointed up and waving frantically in the water. A bright



During my visit to the Penguin Ranch, where scientists are studying the diving habits of emperor penguins (below), I also got to observe human divers, in this case Kevin Hoefling and Ben Hunt from Art DeVries's fish group. These guys had it much harder than I did: They had to dive through an exposed hole in the ice miles from McMurdo Station, while I dove from the protected shelter of a fish hut. (Notice the slushy ice around this diver who has just emerged from below).

# OM OF THE WORLD

yellow snail the size and shape of a softball had anchored itself to the sea floor. As I swam along the reef, I saw a blanket of hundreds of white eggs on a rock before I noticed a fish with a long pointed snout hovering above it. The fish darted toward me, mouth open and teeth bared, to drive me away from the nest he was protecting.

This was a dragon fish, *Gymnodraco acuticeps* (above left), one of the species of fish studied by Dr. Art DeVries of the University of Illinois, who's been working in Antarctica for nearly four decades. For years, scientists had wondered how these animals survive in what should be a physiologically impossible environment. In particular, how do they keep their blood and bodies from freezing in water that is twenty-eight degrees Fahrenheit (-2° C)? When he was a graduate student here, Art discovered a unique biological adaptation that keeps these fish alive.

Antarctica wasn't always so cold. Thirty million years ago, the water was well above freezing and many different families and species of fish thrived in Antarctic waters. But when the other continents broke away, a cold ocean current plunged Antarctica and its surrounding waters into a deep freeze.

BEST COPY AVAILABLE

Most fish species died off, leaving one group that had a biological advantage the others didn't have. This group, known as the *notothenioids*, has a gene mutation that converts a common stomach enzyme into an "antifreeze" protein that inhibits the growth of ice crystals. Without this protein, all the fishes that now thrive in these icy waters would freeze solid. From a single mysterious ancestor that developed the first antifreeze gene, new fish species arose and evolved like Darwin's famous Galapagos finches to fill niches in this rich marine environment. Art DeVries considers this underwater environment a unique biological observatory for studying adaptation and evolution in response to intense environmental pressure.

## FROM FISH TO PENGUINS

The polar seas are among the richest ecosystems on earth for organisms which, like the notothenioids, have adapted to survive in extreme conditions. For half the year, much of Antarctica is plunged into darkness, and ice covers the sea for hundreds of miles around the continent. But when spring returns at the end of September, the sun warms the land and the ocean. The sea ice begins to thin and light penetrates the crystal-clear water. At the same time, currents welling up from the ocean floor carry nutrients to the surface. This revs up photosynthetic microorganisms, which, as midsummer approaches, bloom in an explosion of life that turns the clear sea into a rich brown or pea-soup green. This dense mass of single-celled organisms feeds tiny, shrimplike crustaceans called *krill*, which swarm in vast schools and provide food for fish, penguins, seals, and even the largest baleen whales. The entire Antarctic marine ecosystem depends on this base of microorganisms and krill, arguably the simplest and most productive food chain on earth.

Krill are particularly important to penguins. The little Adélie penguins feed directly on krill, while the larger emperor penguins grow fat on fish that depend on krill. I was lucky enough to see and learn about the unique adaptations of emperor penguins during a visit to the Penguin Ranch, a research camp located on the sea ice off McMurdo Station.

The camp is headed by Dr. Paul Ponganis, a research biologist and anesthesiologist from the University of California at San Diego. Paul has been studying these flightless birds for a decade and is particularly interested in the diving physiology of the four-foot-tall emperor penguins, who can stay underwater for up to twenty minutes and descend to depths of fifteen hundred feet (450 m) below the surface. This is an amazing biological accomplishment, especially for a bird, rivaled only by the deepest diving mammals, such as elephant seals, Weddell seals, and whales.

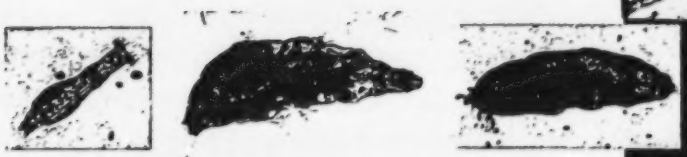
At the Penguin Ranch, five penguins were living in a fenced corral with two diving holes carved out of the sea ice. The penguins were free to dive as much as they wanted, but they also seemed quite content to hang out on the surface and groom themselves. Some of the penguins had devices attached to their backs: video cameras, depth recorders, or monitors for recording the birds' heart rates underwater.

From his work at the Penguin Ranch, Paul Ponganis has learned that emperor penguins can survive longer without breathing than most mammals can. They store more oxygen in their muscles, and they also conserve energy because their streamlined shapes and powerful wings allow them to glide through the water very efficiently. Emperor penguins can swim up to eight miles an hour (13 kph) and will typically catch five to six fish per dive. As they surfaced in the dive hole, I was surprised to hear how loud the penguin's exhalations were as they recovered their breath.

Besides their diving abilities, penguins are remarkable for the ways in which they've adapted to the extreme climate of Antarctica. Emperor penguins are the only birds that stay on the continent all year, exposed to the harshest winter conditions in the world. In the complete darkness of the polar winter, temperatures can drop to below -49 degrees Fahrenheit (-45° C). It's the job of the male emperor penguins to incubate and hatch the eggs in the winter while the females return to the sea and feed.

BEST COPY AVAILABLE

*Right: The earliest explorers of the Dry Valleys never suspected that life could exist in such a dry, harsh environment. When I camped there, I saw only seal mummies, people, and a lone gull-like skua flying in from McMurdo. It wasn't until biologists started looking closely in the soils and under the lake ice that they found tiny ecosystems of bacteria, worms, and other microscopic invertebrates.*



*From left to right:* a rotifer, two tardigrades, and a nematode

*Opposite page: Julie Konop and I spent New Year's Day at this Adélie penguin colony at Cape Royds, the southernmost breeding colony in Antarctica. The penguins need bare, ice-free rock to build their nests and raise young, limiting their choices of breeding sites.*

The males do not eat for three months, but they manage to feed the chicks with an oily secretion they produce for that purpose. Fasting, incubating eggs, and feeding newly hatched chicks during the coldest part of the Antarctic winter is an incredible physiological feat, and the males lose 50 percent of their body fat in the effort. Incredibly, a typical male will regain his body fat in only a few weeks of feeding at sea after he relinquishes the chick back to his mate. This heroic parenting effort is only possible because these birds live and feed in one of the most abundant marine ecosystems on earth.

## FROM ABUNDANCE TO MARS ON EARTH

I saved the best for last: the Dry Valleys. These unique polar deserts are the largest ice-free area in Antarctica, where the cold temperatures and lack of moisture mimic environmental conditions on Mars. The surrounding Transantarctic Mountains act like a dam, blocking the migration of the ice sheet and keeping the valley floors rocky and dry. Yet somehow in this hostile environment, life has gained a foothold.

I flew by helicopter to Lake Hoare, a turquoise-blue frozen lake nestled next to a glittering wall of ice, the Canada glacier. My first day there, I was introduced to the glacier by geologist Andrew Fountain from Portland State University. A member of the Long Term Ecological Research Project (LTER), Andrew's job is to understand how water from the glacier flows into the lake and surrounding soils. In this coldest, driest desert on earth, glaciers are the primary source of water.

With water comes life: The delicate but complete ecosystem of the Dry Valleys is built upon single-celled microbes, which in turn support larger invertebrate life forms, such as predatory nematode worms, rotifers, and tardigrades (also known as water babies). These terrestrial invertebrates—most of which can't be seen by the naked eye—are the largest creatures here, with the exception of visiting humans and the occasional seal or penguin that has lost its way.

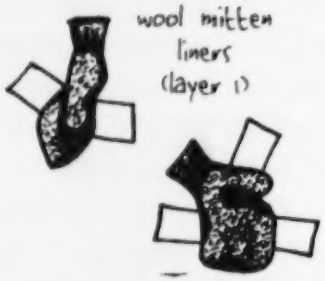
Even the tops of the glaciers provide a refuge for life. Soil blown from the valley floor collects on the glacier, creating pools of dirt and water called *cryoconites*. At temperatures just above freezing, these little pools harbor their own simple ecosystems of microbes and invertebrates, some of which can live for years without making it to the valley floor.

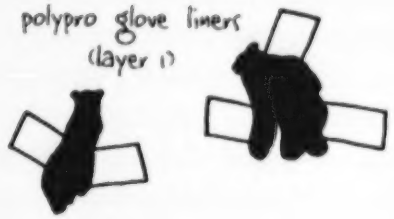
Everywhere scientists have looked in Antarctica they've found life—from nematodes atop glaciers in the Dry Valleys, to snow microbes at the South Pole, to fishes that prowl the underside of the sea ice in McMurdo Sound. These creatures offer a profound lesson on how living organisms adapt and evolve in extreme environments, and continue to respond to changing habitats across the globe. If we look closely and carefully enough, we might even discover how life itself has evolved on earth, and perhaps on other worlds as well. ●

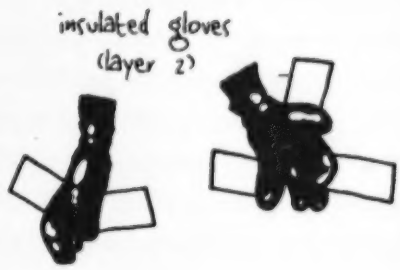
BEST COPY AVAILABLE

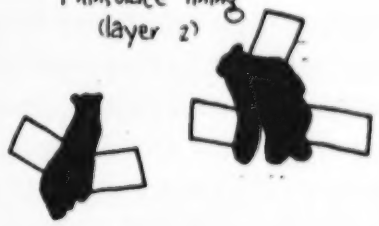
Copy these pages on heavier paper for a sturdier doll.

# DRESS THE SCIENTIST








## TRY THIS! by Taffy Keighley

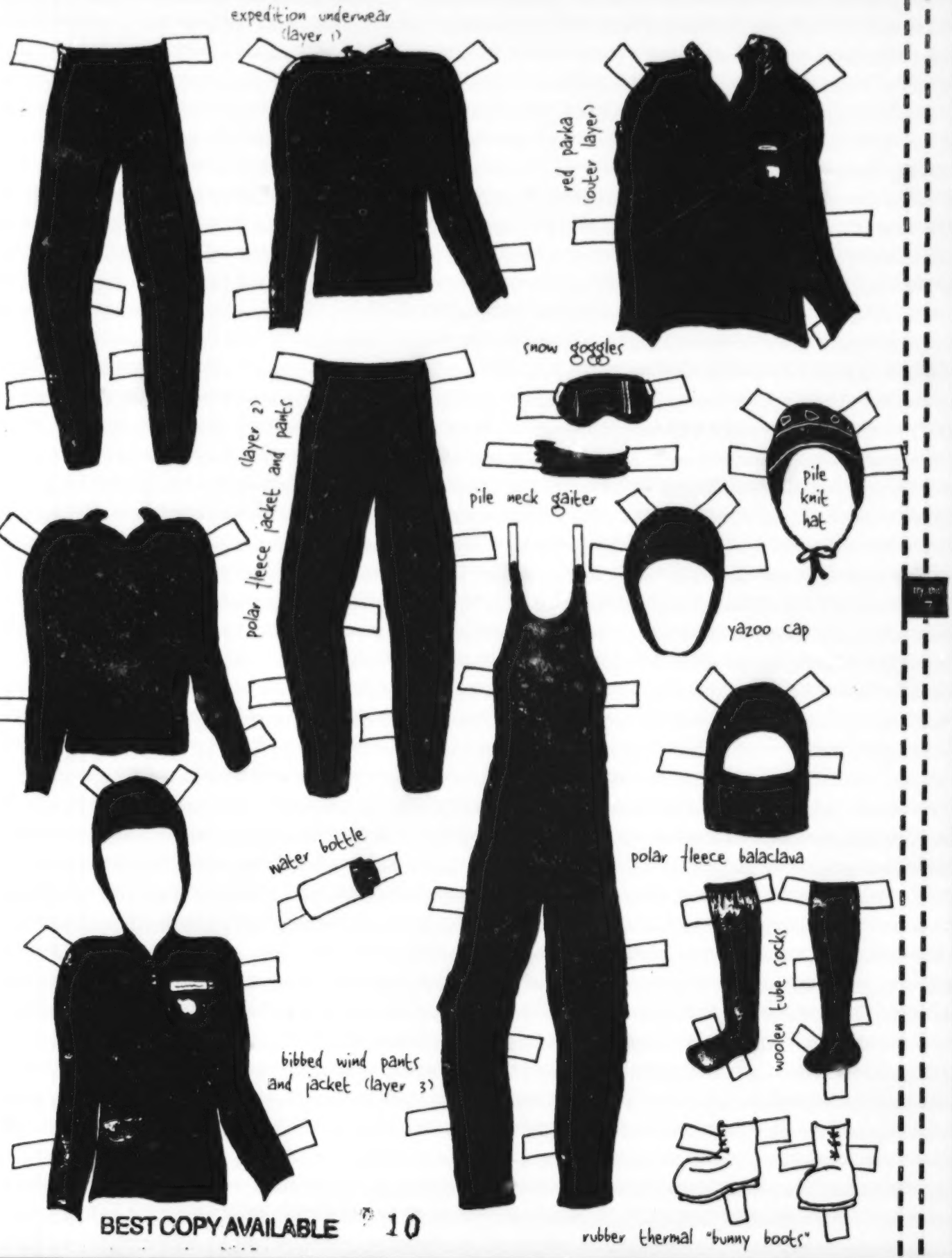
The shivering scientist above has just come to work at the South Pole. He won't last long in his skivvies, though. Winter temperatures can reach -108 degrees Fahrenheit (-78°C), with winds over two hundred miles per hour. So we've provided some of the clothes he'll need "on the ice."

Depending on his mission, you can give him mittens for warmth or gloves for dexterity. Don't forget to protect his eyes, neck, wrists, and ears—and keep his water bottle close to his body so the water doesn't freeze.

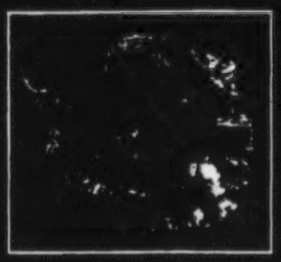
Layer 1 goes on first, then layer 2, and all the rest goes on top. Layers trap insulating air to keep in body heat, but, in addition, he can peel off a layer or two when he's doing strenuous work. (It's important not to get too hot since frozen sweat can get really uncomfortable when things cool off.)

Our little paper scientist can't put on all his protective layers at once, but Mary, Noel, Julie, and Paul sure did. Take a look at the photo on the right and see if you can identify some of the fashionable Antarctic togs. ●

BEST COPY AVAILABLE




BEST COPY AVAILABLE



# SOUTH POLE

by Noel Wanner

The military plane touches down and skis to a halt on the packed snow. The sergeant of the New York Air Guard gives us the thumbs up, and while the engines roar, I stagger out into the freezing air with the other dazed passengers. Pausing for a moment, I look around and find huge emptiness. A white expanse stretching to the faintest of horizons, with sky above, ice below. Though the December summer sun shines brightly, the air is cold, -4 degrees Fahrenheit (-20° C), and filled with a fairy dust of ice crystals reflecting and refracting the light.

This is the South Pole, perhaps the most remote, forbidding spot on earth. But this bleak place is also now one of our best, and most unusual, astronomical observatories. The air here is clearer than anywhere else in the world. There are no sources of electromagnetic interference (like cities!) for thousands of miles in any direction. The atmosphere is at its thinnest at the poles, for the earth's rotation concentrates the mass of atmospheric gases into a bulge at the equator. Plus, the earth's magnetic field steers charged particles towards the polar regions, making the poles excellent locations to observe messengers from the cosmos.

There are currently about ten astronomy projects underway at the South Pole. To see them, I have to walk a little over a mile (2 km) from the silver-domed Amundsen-Scott South Pole station. It's so cold that the snow squeaks under my boots. Finally I come to a low blue building that crouches on stilts, like a squat caterpillar, looking out onto the polar brightness through dark-tinted porthole windows.

The building is the Martin A. Pomerantz Astronomical Observatory, MAPO, the center of astronomical research at the South Pole. At either end of its low bulk, odd white and silver dishes open up to the sky—telescopes! But these don't look anything like your usual telescopes. The scientists call them "instruments," and they're tuned to detect phenomena far outside the range of visible light. The majority of the work here focuses on two of the faintest and most ineffable remnants of radiation from the early universe: the cosmic microwave background radiation, and cosmic neutrinos.

## RIPPLES IN PRIMORDIAL GRAVITY

Oddly enough, the vastness of the South Pole is used to observe some of the smallest echoes from the beginning of the universe. When the universe was in its infancy, it was just a big stew of hot particles: electrons, protons, helium nuclei, neutrinos, and *photons*, particles of electromagnetic radiation. The particles were constantly colliding with one another; a photon couldn't go very far before running into a charged particle, usually an electron, that would scatter it.

About 300,000 years into its nearly fourteen-billion-year history, however, the universe underwent a critical change known as *the last scattering*. All along, the universe had been expanding and cooling, but it now reached a temperature that was cool enough for protons to hold onto electrons, forming hydrogen atoms with no net charge. Suddenly, photons were able to continue along whatever path they happened to be on without obstruction—they'd been scattered for the last time.

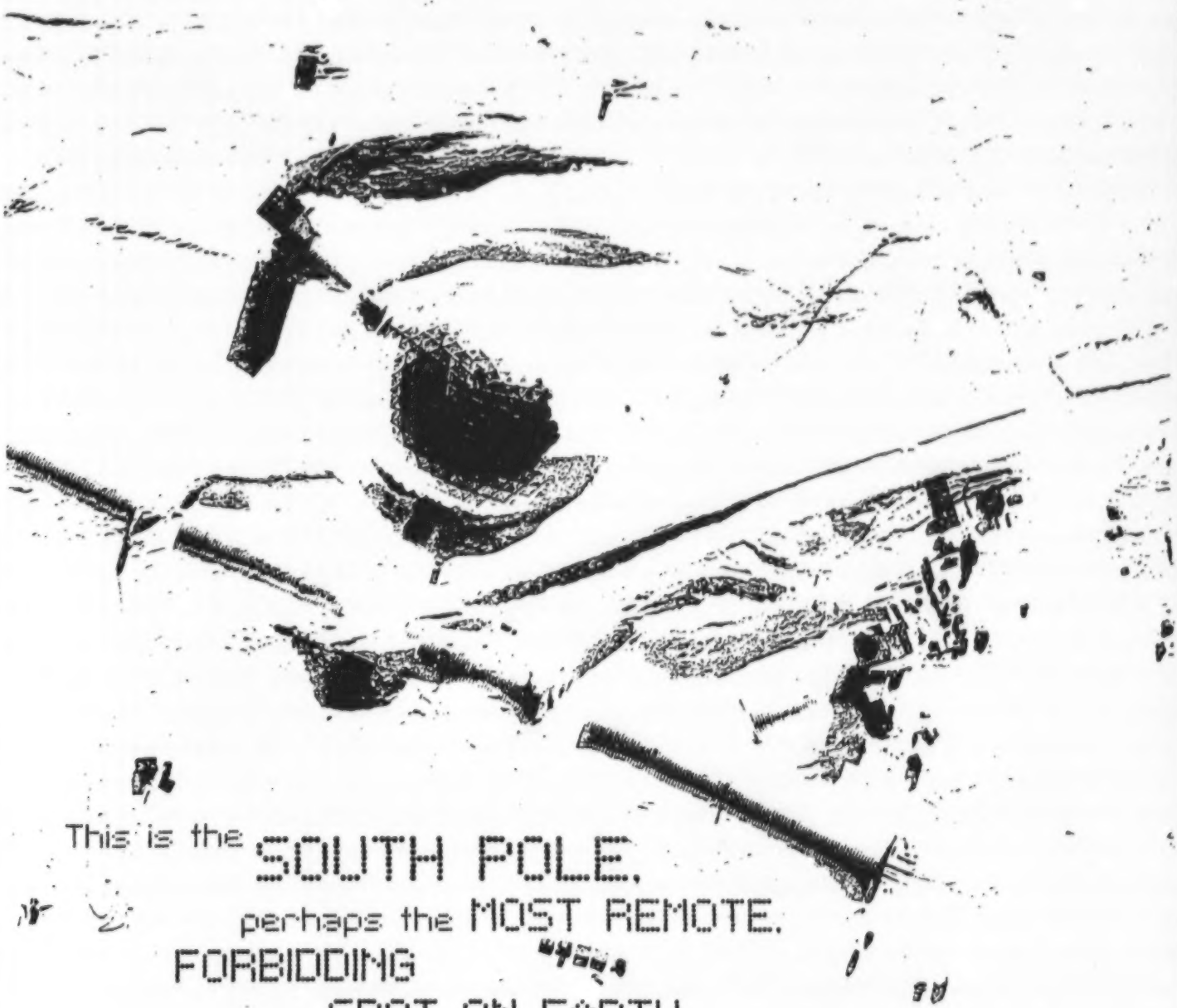
When the photons began their unimpeded journeys, their energy level was in the range of visible light. But the ever-expanding universe has "stretched" that ancient light into invisible microwaves. (See the diagram of the electromagnetic spectrum on page 10.) This is the faint signal that Antarctic researchers are hunting: the *cosmic microwave background*, or CMB.

If the CMB we see now has a long wavelength (a relatively low energy per photon), then we can imagine reversing the stretching caused by the expansion of the universe, moving backwards in time—something physicists have done mathematically. In this scenario, the wavelength of light



BEST COPY AVAILABLE

# ASTRONOMY

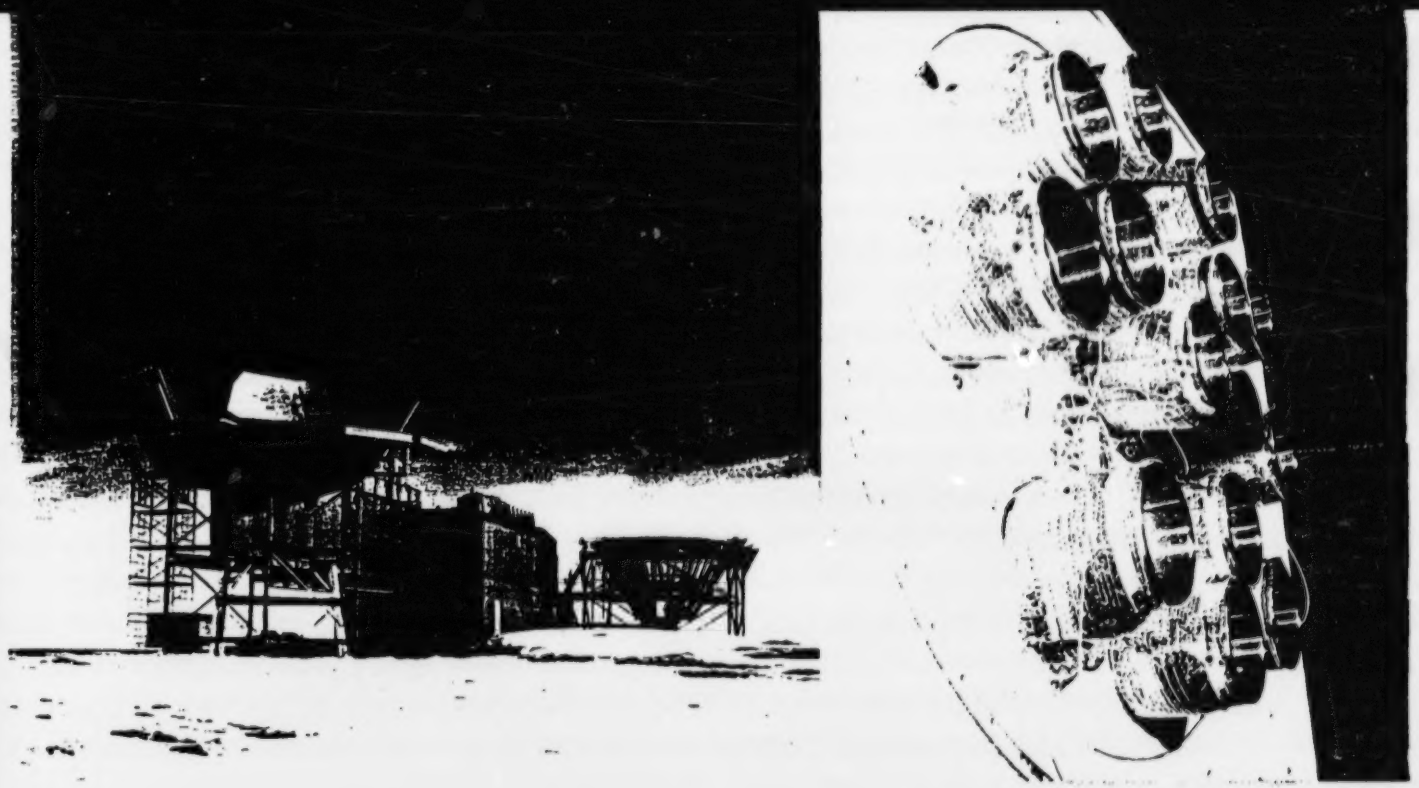


This is the SOUTH POLE,
perhaps the MOST REMOTE,
FORBIDDING
SPOT ON EARTH.

But this bleak place
is also now one of our BEST, and MOST UNUSUAL,

ASTRONOMICAL
OBSERVATORIES.

BEST COPY AVAILABLE



My first day at the South Pole, I walked out across the ice runway to find MAPO, the last building before the endless expanse of ice. The weird white-and-silver thing (shown in close-up on right) is DASI (Degree Angular Scale Interferometer). I learned that each of those silver "eyes" is a directional microwave antenna—a telescope, basically—for looking at tiny fluctuations in the cosmic microwave background radiation. Pretty cool!



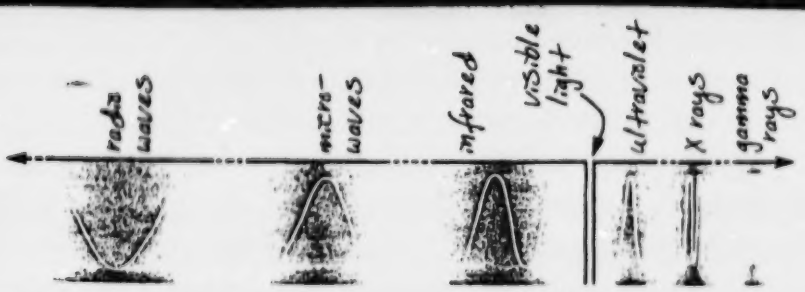
becomes shorter and shorter and matter becomes denser and denser, implying that the universe began in a hot, dense state. So the very existence of the microwave background is thought to be evidence for the big bang theory itself. When you look at the CMB, you are looking backwards in time. As University of Chicago physicist Wayne Hu puts it, "We are bathed in primordial light."

The microwave background radiation that arrives at the South Pole lets scientists see back to when the universe was only 300,000 years old, when radiation "decoupled" from matter, and when the universe began to gain structure and order that would lead to the formation of stars, galaxies, and all the familiar objects of the universe as we know it today. The question is, how did that happen? Scientists are looking at some very old photons to find out.

The temperature of the old photons in the CMB is very cold—about three kelvin above absolute zero (-454° F, -270° C)—and very even. Like a cake set on a rack to cool, the background radiation has had time to cool down evenly. To one part in a hundred thousand, the temperature is the same in any direction. But there are subtle temperature fluctuations sometimes referred to as "ripples," and they intrigue scientists greatly. In fact, scientists think these ripples may help explain how the whole structure of the universe came to be as it is.

Predicted by theoretical physicists, ripples were discovered experimentally in 1992. Since that time, experiments have been designed to look at these ripples with higher degrees of accuracy. At the South Pole, scientists are using a high-resolution instrument called DASI (Degree Angular Scale Interferometer) to enable them to measure these temperature variations with greater precision.

The primordial stew of particles, scientists think, behaved very much like a gas. Gravity tried to compress the "gas," and the pressure of the "gas," in turn, resisted this compression. This tug-of-war set up ripples—essentially, oscillations in the gravity. Some




## Electromagnetic Spectrum

The electromagnetic spectrum is a continuum of electromagnetic radiation that covers a wide range of wavelengths and frequencies from radio waves to gamma rays.

Imagine that you have a wave pattern of short-wavelength light drawn on a rubber band, then imagine that you stretch the rubber band, which stretches out the wavelengths. This is a model for how old light from the early universe was stretched into microwaves.

BEST COPY AVAILABLE

areas of the stew began to have more mass than others. Since gravity increases with mass, the more mass these ripples collected, the more strongly they attracted the particles around them. The more matter, the more gravity—and the process feeds itself.

So from tiny gravitational ripples, the primordial soup of particles could have begun to form structure, resulting in the clustering of huge amounts of mass into galaxies—and within galaxies, the stars, solar systems, nebulae and planets that exist today.

[illegible]

AMANDA ("Antarctic Muon And Neutrino Detector Array") is one of the oddest—most beautiful—astronomical instruments you will never see. The reason you will never see it is because it is buried under thousands of feet of Antarctic ice, just off to the side of the MAPO building. The reasons for this icy burial have to do with the nature of AMANDA's quarry: the elusive neutrino.

Some neutrinos are created in stars like our sun, but the ones AMANDA is hunting are high-energy particles created in hugely violent, energetic events such as supernovae and the formation of black holes. As far as we know, neutrinos have no charge, and nearly no mass. (Until recently, they were thought to have *no* mass at all, but emerging research indicates that neutrinos have some scant mass.) Scientists think these nearly ghostlike particles may tell us a great deal about the nature of the universe. As AMANDA researcher Francis Halzen says, "The hope is that a particle that is almost nothing may tell us everything about the universe."

How can this be? Well, neutrinos are highly energetic, traveling essentially at the speed of light. They interact very weakly with other matter, passing through the universe like elemental ghosts. Even as you read this, neutrinos have zipped through you on their cosmic journey.

But the same thing that makes neutrinos hard to detect makes them a great source of information about very distant galactic events. For supernovae on the other side of the galaxy, for example, neutrinos may be the only remnants we can perceive. Interstellar messengers, they travel endlessly, carrying information from the event that gave them birth.

Fortunately, these invisible ghosts do bump into the earth occasionally. Every now and again, a neutrino collides with a proton or a neutron, and when it does, it gives off an elementary particle called a *muon*. The muon travels away on the exact path that the neutrino was on, giving off a spectral green-blue light called *Cherenkov light* as it speeds away. The lighted path of the muon lets scientists deduce the earlier path of the neutrino.

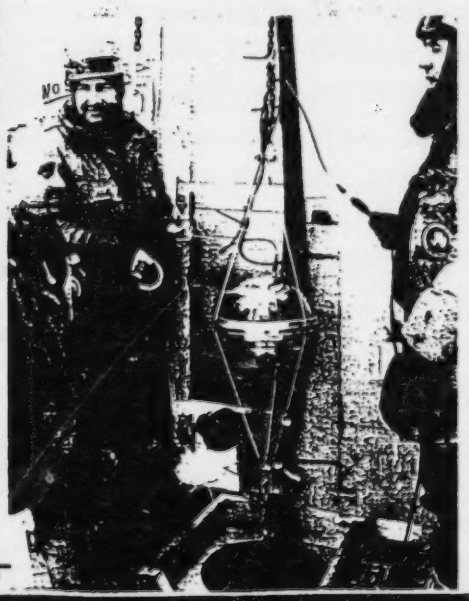
In their attempt to "catch" neutrinos, scientists decided to look for Cherenkov light. They planned to link photodetectors together in a three-dimensional array, which would "see" the path of light as it was created. To do that, they needed a clear, dense substance in which to place their detectors; it needed to be dark, so that the faint light of a neutrino event could be discovered without interference from other light sources. And they needed a big space, filled with lots of detectors, to maximize their chances of seeing the rare neutrino collision.

The two obvious candidates for locating this big detector array were in the ocean and under the ice. Each is denser than air, which makes it more likely to interact with something, and each also slows the speed at which light can pass through it. In these materials, muons travel faster than light, which produces Cherenkov radiation. But ice has some advantages over the ocean: It doesn't move, no creatures live in it, and there's no pollution of any kind. And the ice deep under the South Pole is nearly optically pure—perfect for neutrino-hunting.

As you walk across the snow outside the MAPO building, the AMANDA detectors are under your feet. The AMANDA researchers used a hot-water drill to tunnel 6,500 feet (2,000 m) down into the ice. Then, while the meltwater was still liquid, they lowered their strings of photodetector globes down into the holes. When the ice refroze, the detectors were locked in place, connected to the surface by thin fiber-optic cables that carry the detectors' signals back to the banks of computers in MAPO. From there, the data can be processed and relayed to scientists all over the world.

As I trudged back to the half-buried dome of the main station, cold and looking forward to a mug of tea in the galley, I wondered at the paradox. This emptiness, this wasteland that was once visited by only the hardiest of explorers, has proved to be an invaluable astronomical research location. In this impossible silence, in this terrifying emptiness, scientists "listen" to the faint echoes of the birth of the universe, hoping to trace the mechanisms by which our small blue-green planet came to be. ☺

The spooky thing about AMANDA is that this vast array of photodetectors is completely invisible from the surface. I had to imagine the team drilling dozens of deep holes in the ice, then lowering their strings of light sensors to be frozen in the pure, clear darkness of the ice. Katherine Rawlins, one of the AMANDA researchers, gave me these pictures of the drilling rig and of a photodetector about to be lowered into the melted hole, to help me understand the process.





BEST COPY AVAILABLE

# GROUND TRU

geology
12

To a geologist, "ground truth" is all-important. Geologists must go to a site, observe the geology firsthand, and gather samples of rocks and soil. How, I wondered, did geologists in Antarctica, 98 percent of which is covered with ice, find ground truth? I was about to find out.

As a member of the Exploratorium expedition to Antarctica, I was on my way to the largest American base, McMurdo Station, to meet three teams of geologists. I would learn that the first team was studying the surface layer of the ice itself—gaining "ice truth" by measuring the flow of the glaciers in the Dry Valleys. The second team was using a group of dormant volcanic cones that stick up through the ice to study stresses within the crust of the earth, and the third team was investigating Mount Erebus, an active volcano that towers above McMurdo Station.

BEST COPY AVAILABLE

## THE DRY VALLEYS

On a bright December morning, a Huey helicopter transported me from McMurdo Station across the hundred-mile-wide (160-km-wide) ice-covered expanse of McMurdo Sound to the Dry Valleys, an area notable for its bare ground. One of the driest deserts on earth, the valleys receive almost no snowfall. Mountains surround the valleys like brown picket fences, and the strangest-looking glaciers I'd ever seen squeeze down into the valleys between gaps in the mountains. The glaciers spread out into neat semicircles, then end abruptly in hundred-foot-high (30-m-high) vertical ice cliffs.

The helicopter landed at Lake Hoare Camp, right at the base of the ice cliff of the Canada glacier. Glaciologist Thomas Nylen was waiting for me. He and his team, graduate student Sarah Tegt and volunteer Virginia Butler, were anxious to get to the top of the glacier. I rushed to join them as they put on their double mountaineering boots and grabbed day packs, ice axes, and crampons. In addition to the usual equipment, Thomas was carrying a ten-foot-tall (3-m-tall) bamboo pole with a flag on top.

We hiked until we reached a steep ramp that penetrated the ice cliff. Then we put our spiked crampons on over our boots and took our ice axes in hand to make the ascent. Once on top, I spotted a flag-topped bamboo pole sticking out of the ice that looked like the one Thomas was carrying. Thomas explained that we were combining the oldest and newest tools of glaciology. Over a century ago, geologist Louis Agassiz had placed a line of poles across a Swiss glacier and then watched as the poles were carried downhill by the glacier's flow. Thomas uses similar poles, but he measures their positions year after year using global positioning satellites. His satellite receiver records the motion of a pole to within a few centimeters, the width of a human hand.

Thomas's measurements show that the Canada glacier creeps downhill at only a meter per year, a distance about the length of my arm. Glaciers in the Dry Valleys move slowly because they're extremely cold, only about one degree Fahrenheit (–17° C). Frozen solid to the ground below, the top of a Dry Valley glacier rolls forward like the track on a tank. The forward end of the glacier briefly overhangs the rest, then collapses, leaving behind a vertical wall of ice.

The dry winds that flow down the valleys, called *katabatic winds*, cause the broken ice to sublime—to vanish into thin air—leaving the characteristic steep cliffs behind.

The data Thomas has accumulated over a decade will help him figure out the effects of global climate change on the glaciers of the Dry Valleys. His efforts are just one part of a global undertaking to document the climate.

As I flew back to McMurdo Station, I looked to the right and saw the red rocks of dormant volcanoes sticking up through the ice about twenty miles (32 km) away. Soon I'd be investigating these red domes on the flank of Mount Morning.

*It's hard to get a feeling for scale looking at the big photo, but the Dry Valleys' glaciers end in towering, 100-foot cliffs, which you can see in the photo below. At right, Thomas Nylen and Virginia Butler are recording the movements of bamboo poles, which tell them how fast the glacier is flowing. Thomas wore shorts to take advantage of the balmy (40° F) weather.*

BEST COPY AVAILABLE

## MOUNT MORNING

The first time I saw Professor Terry Wilson (who's on the right in the large photo), I admired the well worn character of her double mountaineering boots, which told me that I was in the presence of a hard-working field geologist. It turned out that Terry Wilson is one of the most experienced geologists in Antarctica. This season, she was leading a team that was trying to determine the history of stresses in the crust of the earth in this area. Geologists want to know how and when rifts in the earth opened up beneath Antarctica and became full of seawater. Understanding these stresses in the earth might help us comprehend the recent history of continental drift near Antarctica and also help us know why Antarctica has the least seismic activity of any of the continents.

Terry was trying to find the stresses by searching for their effects. On previous trips, she had noted that a number of dormant volcanic cones seem to be lined up along the sides of McMurdo Sound, which is an ocean-filled rift area. She wanted to gather data on the position of every visible volcanic cone to determine if the alignments were real or just a human misperception. If these cones do line up as suspected, it can be assumed that volcanism was connected to the spreading of the rift, and that dating the volcanoes will date the rift activity.

Terry invited me to join her team on one of their expeditions. We flew out in a helicopter for a half-hour trip across McMurdo Sound, watching Mount Morning come more clearly into view. The lower part of the mountain facing the sound was covered with dozens of volcanic cones. As we got closer, I could see that they rose a hundred feet (30 m) or more above the lava and ice. With central bowl-shaped depressions, they resembled sports stadiums without roofs.

The team spent about an hour taking photographs and videos of every volcanic cone over hundreds of square miles. After all the cones were photographed from the air, we landed in the bowl of one of the cones to acquire ground truth—rock samples.

BEST COPY AVAILABLE

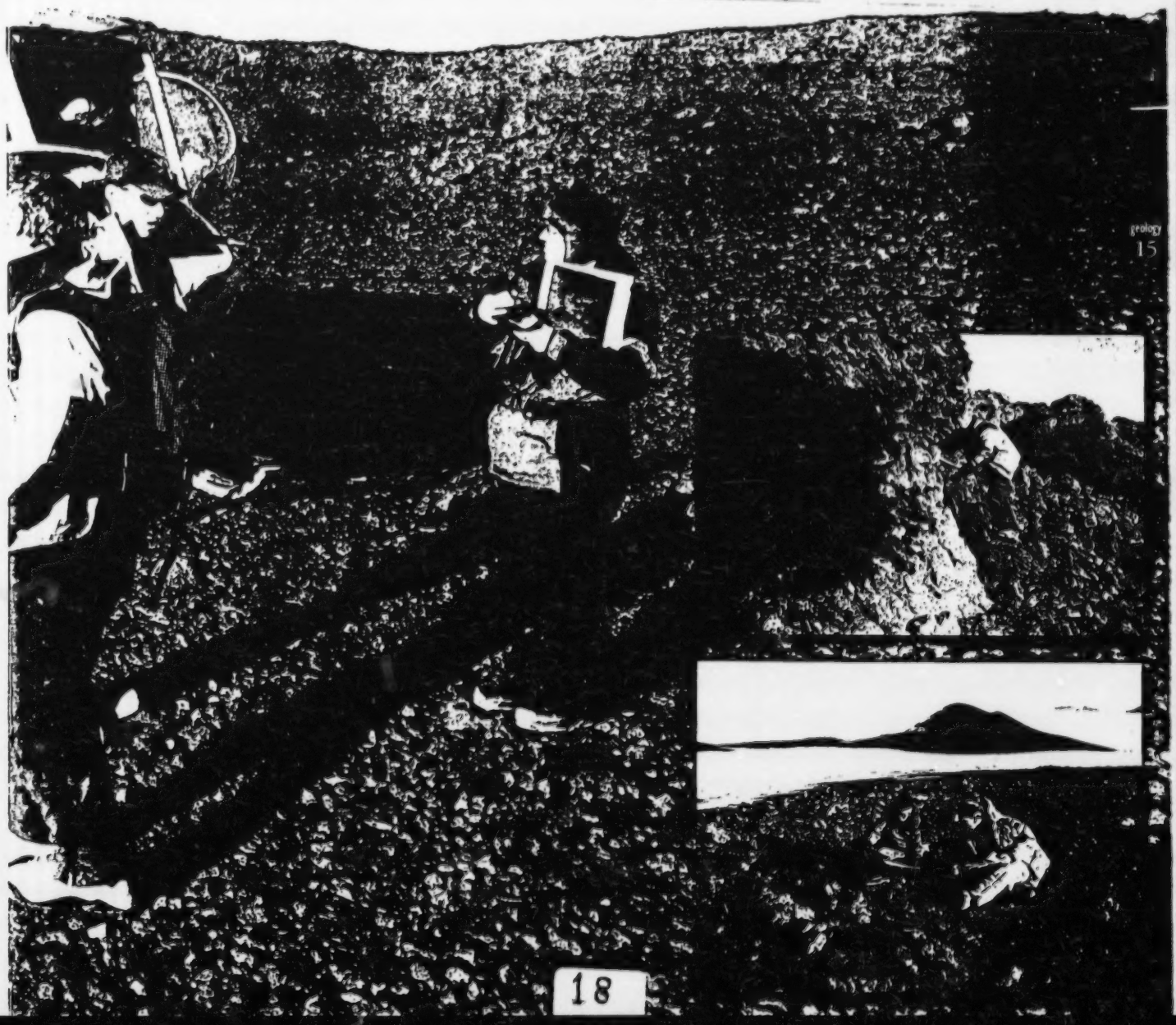
To record the locations of the rocks, Terry's team inscribed lines on the bedrock of the volcanic cones and then used precision compasses to orient these lines. Finally, they removed these marked chunks of bedrock with blows from sledgehammers. The bedrock samples would be taken back to the laboratory to be dated by radioactive decay, which tells geologists the date at which the lava crystallized. To double-check the age of these rocks, the magnetic field preserved in the cooling lava would also be measured.

While the geologists gathered their samples, I took a moment to look around. Bright red layers of rock surrounded me as I stood on boulders polished by windblown snow. As I examined the landscape, one of the geologists said, "You know, we're the first people to ever set foot on this place." I was awestruck.

As I was returning to McMurdo Station, I looked across the sound to my next goal, the smoking summit crater of Mount Erebus, rising over twelve thousand feet (3,600 m) above sea level.

I shot the large photo right after our helicopter landed on one of the volcanic cones that dot Mount Morning. As soon as they were on the ground, Terry Wilson (right), Jon Koenig (center), and Peter Braddock (left) began looking around for a bedrock outcrop.

Peter is collecting rock samples in the photo below. Peter's a mountaineer as well as a geologist. (You can't go climbing in Antarctica unless you've got a mountaineer with you.) In the bottom photo below, Terry and Tim Paulsen are recording data on the spot. You can see another of the volcanic cones rising up behind them.



## MOUNT EREBUS

Once again, my trip began with a helicopter ride. Our team was whisked uphill to Tent Camp, 9,300 feet (2,800 m) above sea level, where we spent two days allowing our bodies to adjust to altitude. Then we flew to Lower Erebus Hut, at 11,300 feet (more than 3,000 m), and just one-and-a-half miles (about 2.5 km) from the crater of Mount Erebus, a volcano that erupts three times a day.

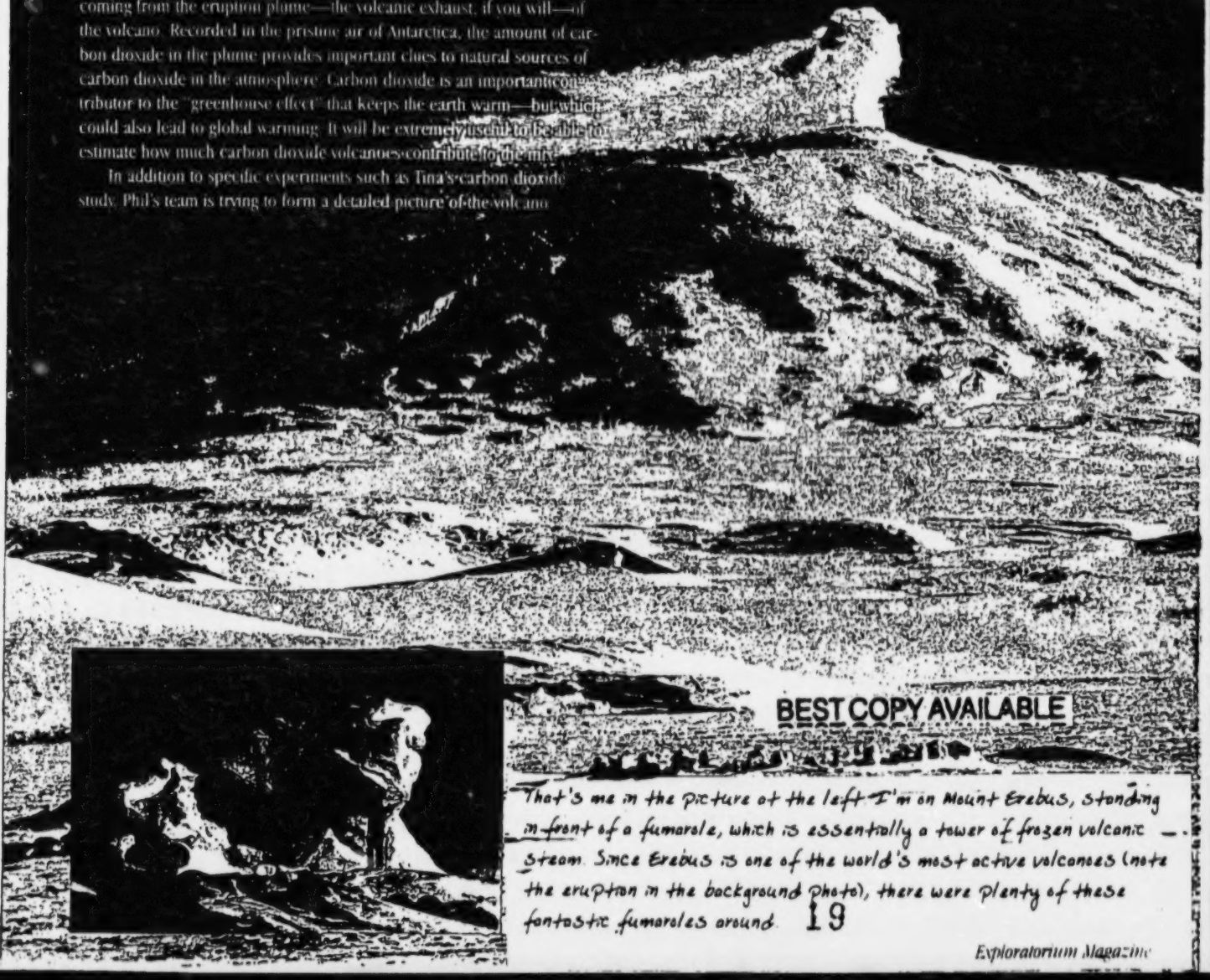
We were welcomed there by Professor Philip Kyle from the New Mexico Institute of Mining and Technology, who's led the research on Mount Erebus for the past three decades. Over tea, he told us that Erebus is a rare volcano in many respects. Most importantly, it has a molten lava lake in the summit crater that provides a direct connection to the magma chambers full of molten rock deep inside the volcano. It's one of only a few volcanoes in the world in which an active lava lake has endured for decades. Phil told us that the lava lake is the volcanic equivalent to having a window placed in a human chest so you can watch the heart beat. This lava lake lets geologists study the magma and gases inside Mount Erebus.

Gases escape from the magma inside the volcano and rise through the lava lake into the atmosphere. During my visit, graduate student Tina Galvin was using a spectroscope to measure the amount of carbon dioxide coming from the eruption plume—the volcanic exhaust, if you will—of the volcano. Recorded in the pristine air of Antarctica, the amount of carbon dioxide in the plume provides important clues to natural sources of carbon dioxide in the atmosphere. Carbon dioxide is an important contributor to the "greenhouse effect" that keeps the earth warm—but which could also lead to global warming. It will be extremely useful to be able to estimate how much carbon dioxide volcanoes contribute to the mix.

In addition to specific experiments such as Tina's carbon dioxide study, Phil's team is trying to form a detailed picture of the volcano over time. A Webcam, for instance, is constantly recording eruptions. Seismographs and global positioning satellite (GPS) recorders are additional tools. The seismic data Phil's team records come from small earthquakes that erupt along the edge of the magma chamber. By listening to the seismic waves coming from each earthquake at several seismic stations, the geologists can build a three-dimensional model of what's going on underground.

Data from the GPS recorders show external effects. The magma chamber of Erebus inflates and deflates with the ebb and flow of lava, actually changing the volcano's shape. Changes in the positions of the GPS receivers that surround Erebus reflect the movement of the magma chamber. The GPS team was led—most impressively?—by an undergraduate student, Emily Desmaraus. I met her briefly before she sped off on her snowmobile to retrieve data from her receivers.

Antarctic geologists work in one of the harshest environments on earth. Yet despite the cold and discomfort, you can see the fire in their eyes. They're passionate about the unique opportunities Antarctica gives them to pry information from ice and rocks and to learn just a little better how the earth works.



BEST COPY AVAILABLE

That's me in the picture at the left. I'm on Mount Erebus, standing in front of a fumarole, which is essentially a tower of frozen volcanic steam. Since Erebus is one of the world's most active volcanoes (note the eruption in the background photo), there were plenty of these fantastic fumaroles around.

# MAJOR DONORS

Our thanks to those who have helped the Exploratorium continue in its role as a leader of science education and a valuable resource for the Bay Area. We gratefully acknowledge contributions of $1,000 or more made from March through May 2002. We particularly appreciate the generous support of the Grants for the Arts/San Francisco Hotel Tax Fund, the California Arts Council, the California Department of Education, the Institute of Museum and Library Services, the National Endowment for the Arts, the National Institutes of Health and the National Science Foundation.

**$50,000 and above**
American Honda Foundation
Amgen Foundation, Inc.
Bank of America Foundation
Bechtel Group, Inc.
Carnegie Corporation of New York
Genentech Foundation for Biomedical Sciences
Metible Foundation
Sony Corporation
Marin Community Foundation
Wells Fargo

**$10,000 to $49,999**
Accenture, LLP
Chiron Corporation
Cooley Godward LLP
DeMarco Barbieri Family Fund
Franklin Templeton Investments
Evan and Mary Helfet
Bill and Melinda Gates Foundation
Genentech, Inc.
Harvey W. Glasser and Gail K. Glasser
Peter V. and Marion Hooley
JPMorgan Chase
KPMG, LLP
The Stanley S. Langendorf Foundation
Linzagetchventures
Technispeed Venture Partners/Gail Cassou
The Joseph R. McMicking Foundation
Merrill Lynch & Co., Inc.
Gordon and Betty Moore Foundation
Ruediger Naumann-Etienne and Annette Campbell-White
Oracle Corporation
The Osborn Family Foundation
Stelios Papadopoulos
The Pyeboat Family
Polatnick Properties
Dr. William J. Rutter
Seneca Capital Management LLC
Tom Stever and Kat Taylor
U.S. Venture Partners
Zymogenetics Inc.

**$5,000 to $9,999**
Alah Family Foundation
Allos Ventures, Inc.
Gerson and Barbara Bakar Philanthropic Fund
Bank of America
BioMarin Pharmaceutical Inc.
Bowes Inspired Value Fund, L.P.
Robert and Dana Bloom
John M. Bryan Family Foundation
Cahill Contractors Inc.
Cassidy Charitable Gift Fund
Anne M. Chavez and Eugene Eidenberg
Cisco Foreign Corporation
Custom Fund Management LLC
Bob Epstein and Amy Ruth
Helen and Laura Fisher Fund
The 49ers Foundation
John and Barbara Glenn
Richard N. Goldman
Mimi and Peter Haas
Walter and Elise Haas Fund
Hoover Investment Management Co., LLC
The Horet Family
Hyseq Pharmaceuticals, Inc.
ICOS Corporation
Merrill and Van Kooper
Laura and Gary Lauder
Tom Lockard and Alex Marduel
Vernon R. Loucks, Jr.
The Markkula Foundation
Dr. and Mrs. Robert M. Metcalfe
Pacific Growth Equities
Regel Pharmaceuticals Inc.
Jean and Arthur Rock
Rutherford & Chekene
The Schwab Fund for Charitable Giving
Charles and Helen Schwab Family Foundation
Leonard J. Shustek Philanthropic Fund
Barclay and Sharon Simpson
Bonnie and Marty Tenenbaum Foundation
Wendell Family Foundation
Hyseq Pharmaceuticals
Anonymous

**$2,500 to $4,999**
Altometrics, Inc.
Gene Soft Inc.
Grant Thornton LLP
Hobson Family Foundation
B. Marcia Sanders

**$1,000 to $2,499**
Dr. Bruce M. Alberts
Mr. and Mrs. G. Leonard Baker, Jr.
Cornerstone Capital Services
Cepheid Inc.
Farah Champsi
Chiesco Family Foundation
Jean and William Coblentz Philanthropic Fund
Bruce and Eve Cohen
Marion A. Davis and Anthony L. Bresnie
The Draper Foundation
Keith G. Eickmeier
Elizabeth and David Evans
Ann and Gordon Getty Foundation
Ron Gutcher
Dr. Adele E. Goldberg and Dennis Allison
The David B. Gold Foundation
Dr. and Mrs. Arthur Kornberg
KPIX Television
Julius R. and Patricia A. Krevans
Kristen and Tim McCarthy
Mr. and Mrs. Edwin R. Mahin
Mr. and Mrs. L. Addison Marchell
John S. Osterweis Philanthropic Fund
Dr. and Mrs. Wolfgang K. Panofsky
Jacqueline Pitou
Mr. and Mrs. Burton Richter
Jeanne and Sanford Robertson Fund
Heather Schwartz and Frank Lowther
Robin Silver
Stacey and Jeff Solomon
Paul H. and Elizabeth M. Stephens Fund
Eric and Stephanie Telemus
Dr. and Mrs. James D. Watson
Dr. Irving Weissman
Allison G. Williams and Walter S. Cohen
Mr. and Mrs. Leonard R. Weisfeld

# CREDITS

ALL MAPS: Photo courtesy of NSF. FRONT COVER: Photo montage by Taffy Reighley; (top): photo courtesy of Paul Doherty; (bottom): photo courtesy of NSF. INSIDE FRONT COVER (upper left): Photo courtesy of NSF. PAGE 1: (top left): Photo courtesy of Mary K. Miller; (top center–right): photos courtesy of Noel Wanner. PAGE 2 (top): Photo © Kevin Harding. PAGE 3: Photos courtesy of Noel Wanner. PAGE 4: Photo courtesy of Mary K. Miller. PAGE 5 (middle): Photos courtesy of Dr. Peter Jennings; (top right): photo courtesy of NSF. PAGE 6 (lower right): Photo courtesy of Robert Greenler. PAGES 6–7: Illustrations by Taffy Reighley. PAGES 8–9: Photo courtesy of NSF. PAGE 10 (top left): Photo courtesy of John Kosec; (top right): photo courtesy of Noel Wanner; (bottom): illustration by Taffy Reighley. PAGE 11: Photos courtesy of Katherine Rawlins/AMANDA. PAGES 12–16: Photos courtesy of Paul Doherty. PAGE 17: Photo © Guillaume Dargaud/RAPSODIA. BACK COVER: Photo courtesy of Noel Wanner. NOTE: We make every effort to trace copyright holders prior to publication, but are not always successful. If notified, we will be happy to amend the acknowledgments in a future issue.

We would like to be informed of recognitions your generosity deserves. Please contact the Development Department at (415) 561-0303 to let us know of any omissions.

design by 17

## NEXT ISSUE

This coming October, we're pleased to present *Waterscapes*, a 2003 calendar that explores the many facets of water. *Exploratorium Magazine* will return in January 2003.



BEST COPY AVAILABLE

*Exploratorium Magazine*
is generously sponsored by
BANK OF AMERICA FOUNDATION.
Bank of America.

www.exploratorium.edu/origins/antarctica

Nonprofit Organization
U.S. Postage Paid
San Francisco, California
Permit Number 10380

exploratorium

**In the Palace of Fine Arts**
**3601 Lyon Street**
**San Francisco, CA 94123**

**Museum Hours**
Summer: Open daily, 10 a.m. to 6 p.m., with extended hours Wednesday to 9 p.m., from Memorial Day to Labor Day.
Winter: Open Tuesday through Sunday, 10 a.m. to 5 p.m., with extended hours Wednesday to 9 p.m., from Labor Day to Memorial Day.

**For More Information**
Recording: 415/561-0360
FAX: 415/561-0307
Visit the Exploratorium's Web site at www.exploratorium.edu

**Admission**
MEMBERS FREE. Adults $10; students (over 18 with ID) and seniors $7.50; people with disabilities and youths (ages 5–17) $6; children 4 and under FREE. First Wednesday of every month FREE. Group prices available.

*The Exploratorium is wheelchair accessible*

******AUTO**3-DIGIT 432
11 MS. GAIL MESSINEO
ERIC/CSMEE DATABASE COORDINATOR
1929 KENNY RD
COLUMBUS OH 43210-1015



*Printed in the United States of America*

SE009145

**U.S. Department of Education**
*Office of Educational Research and Improvement (OERI)*
*National Library of Education (NLE)*
*Educational Resources Information Center (ERIC)*

# REPRODUCTION RELEASE
(Specific Document)

## I. DOCUMENT IDENTIFICATION:

Title: Antarctica: Scientiff Journeys from McMurdo to the Pole. Exploratorium Special Expedition Issue.

Author(s): Judith Brand, Ed.

| Corporate Source: The Exploratorium. Exploratorium; v28 n2 Sum 2002 | Publication Date: 2002 |
|---|---|

## II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, *Resources in Education* (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic media, and sold through the ERIC Document Reproduction Service (EDRS). Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce and disseminate the identified document, please CHECK ONE of the following three options and sign at the bottom of the page.

The sample sticker shown below will be affixed to all Level 1 documents

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

1

Level 1

X

Check here for Level 1 release, permitting reproduction and dissemination in microfiche or other ERIC archival media (e.g., electronic) and paper copy.

The sample sticker shown below will be affixed to all Level 2A documents

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE, AND IN ELECTRONIC MEDIA FOR ERIC COLLECTION SUBSCRIBERS ONLY, HAS BEEN GRANTED BY

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

2A

Level 2A

X

Check here for Level 2A release, permitting reproduction and dissemination in microfiche and in electronic media for ERIC archival collection subscribers only

The sample sticker shown below will be affixed to all Level 2B documents

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

EXPLORATORIUM
www.exploratorium.edu

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

2B

Level 2B

X

Check here for Level 2B release, permitting reproduction and dissemination in microfiche only

Documents will be processed as indicated provided reproduction quality permits.
If permission to reproduce is granted, but no box is checked, documents will be processed at Level 1.

*I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce and disseminate this document as indicated above. Reproduction from the ERIC microfiche or electronic media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries.*

**Sign here, please**

| | |
|---|---|
| Signature: Kurt Feichtmeir | Printed Name/Position/Title: Kurt Feichtmeir, Senior Learning Ta |
| Organization/Address: Exploratorium, 3601 Lyon St. San Francisco, CA 94123 | Telephone: 415-561-0372 FAX: 415-561-0307 |
| | E-Mail Address: kurt@exploratorium.edu Date: 10/23/02 |

## III. DOCUMENT AVAILABILITY INFORMATION (FROM NON-ERIC SOURCE):

If permission to reproduce is not granted to ERIC, or, if you wish ERIC to cite the availability of the document from another source, please provide the following information regarding the availability of the document. (ERIC will not announce a document unless it is publicly available, and a dependable source can be specified. Contributors should also be aware that ERIC selection criteria are significantly more stringent for documents that cannot be made available through EDRS.)

| |
|---|
| Publisher/Distributor: |
| Address: |
| Price: |

## IV. REFERRAL OF ERIC TO COPYRIGHT/REPRODUCTION RIGHTS HOLDER:

If the right to grant this reproduction release is held by someone other than the addressee, please provide the appropriate name and address:

| |
|---|
| Name: |
| Address: |

## V. WHERE TO SEND THIS FORM:

| |
|---|
| Send this form to the following ERIC Clearinghouse: |

However, if solicited by the ERIC Facility, or if making an unsolicited contribution to ERIC, return this form (and the document being contributed) to:

**ERIC Processing and Reference Facility**
**4483-A Forbes Boulevard**
**Lanham, Maryland 20706**

**Telephone:** 301-552-4200
**Toll Free:** 800-799-3742
**FAX:** 301-552-4700
**e-mail:** info@ericfac.piccard.csc.com
**WWW:** http://ericfacility.org